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Formation of Elements of Yield Structure and Quality of Mustard Seeds Depending on Genotype and Mineral Nutrition

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Abstract

Given the steady increase in the Earth's temperature in the context of global climate change, which negatively affects the growth and development of most crops, the search for sustainable ecologically adapted plant species and ways to maintain their yields is of great practical importance. Mustard is one of the crops that can grow in drought conditions, which is driving demand for it. The article presents the results of studies of the peculiarities of the formation of the crop structure elements, yield and quality of mustard seeds depending on varietal characteristics and mineral nutrition. It was found that the application of phosphorus-potassium fertilizers, both main application and together with foliar fertilization with nitrogen fertilizers, provided a significant increase in the yield structure indicators – plant height in all phenological phases of mustard growth and development, the number of stems and pods per plant. The greatest increase in plant height of all varieties in phenological phases of growth and development, the number of stems and pods per plant was with the integrated use of phosphorus-potassium fertilizers as the main application and two-time foliar fertilization with nitrogen fertilizers. Indicators of the yield structure elements significantly depended on varietal characteristics. If in the rosette phase, the influence of the "fertiliser" factor was 71.0%, the "flowering" factor – 86.7%, and in the bud and ripening stages the influence of fertilizers was less and amounted to 47.2% and 38.3%, respectively, the influence of the "variety" factor was the greatest in the bud stage and amounted to 48.6% and in the ripening phase – 39.4%. The increase in yield structure indicators contributed to the improvement of mustard seed productivity - while on average, seed yield significantly increased with the use of mineral fertilizers compared to the control - without fertilizers, then seed quality – germination energy and germination, when applying mineral fertilizers did not provide a sufficient increase in these indicators, they were at the level of control and only the weight of 1000 seeds significantly increased both depending on the genotype and the use of mineral fertilizers, which provided an increase in the yield of seeds of all varieties.

Keywords

Geodetic support; GIS; Topographic and geodetic works; State geodetic network; Natural resources

Introduction

Oilseeds are a vital part of agriculture in many countries around the world (Srivastava *et al.*, 2024). The demand for oilseed crops regularly increases due to population surges, dietary choices, and biodiesel product requirements. Oilseed crops are the foremost source of vegetable oil due to their use for culinary purposes (Shah *et al.*, 2023). They are widely used in the food industry because they are healthy and have good functional properties (Zhang *et al.*, 2023). Among others, mustard is an important oilseed crop that can be grown even in arid and semi-arid regions (Shah *et al.*, 2023; Singh *et al.*, 2023), which is essential given global climate change.

It is known that mustard has been cultivated for various purposes since 3000 BC. It has been widely used as a spice and as an energy crop (Grygier, 2023; Kayacetin, 2020). The total area under mustard cultivation in the world is about 3.0 mln ha, with production and yields of 72.37 mln tons and 1980 kg/ha, respectively (Kalia *et al.*, 2021; Stankevych *et al.*, 2020). Ukraine is among the top ten world leaders in terms of mustard cultivation. This crop ranks fourth in oilseed production, following rapeseed, soybeans, and sunflower. (Petrova, 2020). The main external consumers of mustard seeds produced in Ukraine are European countries, which exported 14.3 tons of seeds in 2021 (Kolosok and Melnyk, 2023). In 2007, the area under mustard in all categories of farms was 173.57 thousand hectares, but since 2015 it has been significantly decreasing to 58.8 thousand hectares, while the seed yield has increased from 0.50 to 0.74 t/ha (Mykolayko and Karpuk, 2023). Seed yields and mustard oil quality depend on genetic characteristics, and environmental and agronomic growing conditions, such as irrigation, sowing fertilization, etc. (Kayacetin, 2019). Since Ukraine lacks environmentally adapted zonal technologies for growing mustard, which is a constraint to expanding its cultivation (Zhuykov *et al.*, 2024) and given the growing demand for its seeds, research into ways to increase its yield is relevant.

Insufficient implementation of modern cultivation and protection technologies is the main reason for the low productivity of mustard (Kumar *et al.*, 2020). One of the elements of modern technology in growing crops, including mustard, is balanced plant nutrition, which ensures an increase in both crop yields and the quality of grown products (Zolkin *et al.*, 2022). Fertilizers are one of the factors ensuring an increase in seed yield and quality improvement with simultaneous soil preservation and fertility enhancement (Vassilina, Umbetov and Vassilina, 2012). Mustard requires mineral nutrition throughout the vegetation period, and the maximum demand is reached during the flowering phase. During this period, it requires nitrogen, phosphorus, potassium and other macro- and microelements (Butenko *et al.*, 2022; Indira *et al.*, 2021). For the formation of 1 ton of white mustard seeds, 55–60 kg of nitrogen, 25–30 kg of phosphorus, and 25–35 kg of potassium are required. The removal of nutrients per unit of yield is not a constant value and depends on soil and climatic conditions, varietal characteristics and elements of cultivation technology (Jia *et al.*, 2021).

Sefaoglu *et al.* (2021) demonstrated that the dose of nitrogen has a direct impact on seed yield. With increasing nitrogen doses, the number of pods per plant, the number of seeds per pod, and the weight of 1000 seeds increased, and, accordingly, the seed yield increased. Nitrogen doses (50, 100, 150 and 200 kg ha-1) increased seed yield by 80.4%, 108.3%, 88.9% and 149.8% compared to the control. According to Rozhkov *et al*. (2024), the highest yield of common mustard seeds (2.72-2.79 t/ha) was formed in the variants of combining pre-sowing

application of $N_{45}P_{45}K_{45}$ and $N_{45}P_{30}K_{30}$ with two variants of foliar fertilisation with different fertiliser mixtures. The increase in the dose of pre-sowing mineral fertilisers, as well as the inclusion of mono-elemental fertiliser Quantum Boron Active in the tank mixtures, did not significantly increase the biological yield of seeds, and the cost of cultivation increased significantly. According to Voloshchuk (2024), on grey forest surface glazed soils, the use of mineral fertilizers as the main fertilizer in a dose of $N_{30}P_{30}K_{35}$ and double fertilization with nitrogen in a dose of N_{30} in the rosette and bud stages provided an increase in leaf surface area by 3.1-5.6 thousand m^2/ha and net photosynthetic productivity by 0.30-0.53 g/m^2 per day and, accordingly, an increase in seed yield by 2.46 t/ha.

Mustard is selective when it comes to nutrient availability in the soil and is also highly sensitive to the soil's physical condition. This sensitivity is evidenced by the variations in the structure of the white mustard crop, which depends on different basic tillage and fertilization methods (Anastasya *et al*., 2024; Fussy and Papenbrock, 2022). Thus, on the background of organic-mineral fertilization (with the predecessor straw left in the field and the addition of $N_{30}P_{30}K_{30}$), the highest mustard yield of 2.05 t/ha was ensured by the flat-cutting system of basic tillage, while the profitability of growing white mustard compared to the mineral fertilization system increased by 93-128%, depending on the system of basic tillage (Kirilyuk, Tymoshchuk and Kalchuk, 2019). Creating favourable growing conditions for mustard plants and the formation of high crop productivity is one of the main tasks that all agrotechnological measures for growing mustard seeds should be aimed at, and one of these measures is the use of mineral fertilizers (Chand *et al*., 2021; Jakubus and Bakinowska, 2020).

These findings and studies highlight the research gaps which signifies the present need for this work. In light of the above facts, this research aims to find out the peculiarities of the formation of elements of the crop structure, yield and quality of mustard seeds depending on varietal characteristics and mineral nutrition. The objective of the study was to find out the influence of varietal characteristics in combination with the use of mineral fertilisers on the formation of elements of the crop structure - stems and pods on plants and their height and, accordingly, to determine the seed productivity of mustard. Identify the factors that influence the formation of these indicators.

Methodology

Study Area

The study on the effect of varietal characteristics and mineral fertiliser application on the formation of the yield structure elements of mustard seeds was conducted under conditions of unstable moisture of the Right-Bank Forest-Steppe of Ukraine at the experimental field of Pavlo Tychyna Uman State Pedagogical University of the Ministry of Education and Science of Ukraine, during 2020-2023. Five varieties of mustard were studied, four white – Etalon, Pidpecheretska, Ariadna and Oslava and one black – Tsarivna Pivnochi.

Research Scheme

The scheme of the experiment provides for the cultivation of seeds without fertilization – control and main application of phosphorus-potassium fertilizers in dose $P_{45}K_{45}$ without fertilization and with fertilization with nitrogen fertilizers in dose N_{15} on the seedlings, as

well as basic fertilization in dose $P_{45}K_{45}$ with two fertilization with nitrogen fertilizers in dose N_{15} on the seedlings and one fertilization with nitrogen fertilizers in dose N_{30} in the rosette-stem phase. The seeding rate was 2 mln seeds/ha, using the conventional line method. Superphosphate (20% active ingredient) was applied as phosphorus fertilizer, potassium chloride (54% active ingredient) as potassium fertilizer, and ammonium nitrate (34.4% of the active ingredient) was used for fertilisation.

Research Methods

Elements of the yield structure by growth and development stages of plants were determined by generally accepted methods of crop variety testing (Melnyk, 2016; Volkodav, 2000), seed yield – by weighing by plots from each replication, seed quality – germination energy, seed germination and weight of 1000 seeds according to the current NSTU (National standard of Ukraine, 2002). In the experiment, 5 varieties were studied, the placement of which was systematic in blocks, where the variants were placed systematically in each block of 4 variants, and 4 replications of each variant were randomised. In total, there were 16 variants and replications of each variety, and 80 in the experiment.

Soil and Weather Conditions

The soil of the experimental plot is podzolic heavy loamy chernozem with a humus content of 3.31%. The reaction of the soil solution is neutral - pH 6.5-6.7. The content of mobile phosphorus and potassium compounds is 80-130 mg/kg, which corresponds to the average availability. The period of sowing and germination in terms of temperature and moisture supply was typical for the zone, except for minor deviations in both average daily air temperatures and the amount of precipitation. In 2021, precipitation was at the long-term average, while 2020, 2022 and 2023 were characterized by a slight deficit.

Statistical Analysis

The reliability of the experimental data was determined by the calculation-comparative method using variance and correlation-regression analyses according to Fisher's method (Fisher, 2006) and methodological recommendations (Ermantraut, Prysiazhniuk and Shevchenko, 2007).

Results and Discussion

Ali (2018) studied the conditions of the Northeastern Forest-Steppe of Ukraine on typical deep medium-humus coarse-dusty medium loamy black soil on loess rocks. It was concluded that an increase in fertilizer rates from $N_{30}P_{30}K_{30}$ to $N_{90}P_{90}K_{90}$ contributed to an increase in plant biometric parameters – increasing the height of white mustard plants by an average of 30%, the number of first-order branches by 3.6-5.1% and the leaf surface area by 9.5-15.8%, compared to the control – without fertilizers. Melnyk *et al.* (2019) observed a notable increase in the morphometric parameters of white at the highest background of $N_{90}P_{90}K_{90}$ fertilizers. The average height of plants was 92.5 cm, which is 11.8 cm higher than in the control, with the number of first-order branches increasing by 1.6 pcs. and amounted to 6.1

pcs. According to Shabbir (2021), in North-Eastern Forest-Steppe of Ukraine, the yield structure of grey mustard was the highest under the dose of mineral fertilizers $N_{90}P_{90}K_{90}$ using Vuxal Boron (3.0 l/ha) + Vuxal Bioamino Plant (3.0 l/ha) and amounted: the number of first-order branches - 4.87 pcs, the number of pods per plant - 68.92 pcs and the number of seeds per pod - 13.76 pcs.

According to our research, the height of the plants varied not only with the application of mineral fertilizers, but also from varietal characteristics in all phenological phases of plant growth and development, both in control and fertiliser applications. The control group without fertilizers showed the lowest plant height during seed ripening in the variety Etalon, while the highest height was observed in the variety Ariadna (Table 1).

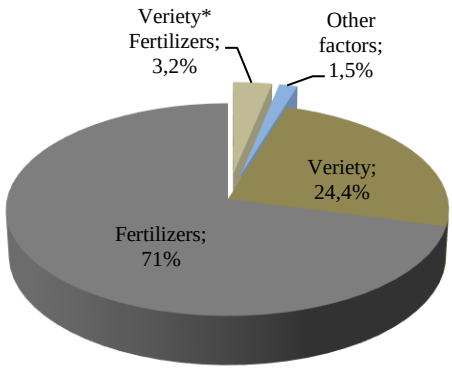
Table 1: Mustard plant height (in cm) depending on varietal characteristics and fertilizer application (average for 2020-2023)

Variant		*Stages of growth and development*			
		rosette	*bud stage*	*flowering*	*ripening*
variety	*fertilizer application*				
Etalon	No fertilizer - control	10.0	34.4	61.7	87.5
	$P_{45}K_{45}$ in the main application without fertilizing	11.0	38.7	69.7	99.6
	$P_{45}K_{45}$ in the main application + fertilizing N_{15} in the seedlings	11.4	39.3	74.6	93.1
	$P_{45}K_{45}$ in the main application + two fertilizers N_{15} in the seedlings + N_{30} in the rosette-stemming phase	11.8	40.7	77.0	102.9
Tsarivna Pivnochi	No fertilizer - control	10.1	39.8	63.6	97.9
	$P_{45}K_{45}$ in the main application without fertilizing	11.6	43.3	71.5	102.2
	$P_{45}K_{45}$ in the main + fertilizing N_{15} in the seedlings	12.3	45.5	77.2	104.3
	$P_{45}K_{45}$ in the main application + two fertilizers N_{15} in the seedlings + N_{30} in the rosette-stemming phase	12.7	47.4	78.8	105.3
Pidpecheretska	No fertilizer - control	9.5	35.4	63.6	97.1
	$P_{45}K_{45}$ in the main application without fertilizing	10.9	38.4	69.0	100.0
	$P_{45}K_{45}$ in the main application + fertilizing N_{15} in the seedlings	11.8	40.7	76.7	101.9
	$P_{45}K_{45}$ in the main application + two fertilizers N_{15} in the seedlings + N_{30} in the rosette-stemming phase	12.0	43.5	78.5	103.4
Ariadna	No fertilizer - control	10.6	42.6	68.2	100.2
	$P_{45}K_{45}$ in the main application without fertilizing	12.2	43.7	71.6	99.9
	$P_{45}K_{45}$ in the main application + fertilizing N_{15} in the seedlings	12.6	46.1	79.3	104.2
	$P_{45}K_{45}$ in the main application + two fertilizers N_{15} in the seedlings + N_{30} in the rosette-stemming phase	13.5	46.4	87.1	103.6

Variant		*Stages of growth and development*			
variety	*fertilizer application*	*rosette*	*bud stage*	*flowering*	*ripening*
Oslava	No fertilizer - control	10.5	36.1	64.4	98.0
	$P_{45}K_{45}$ in the main application without fertilizing	12.5	40.4	73.2	105.9
	$P_{45}K_{45}$ in the main application + fertilizing N_{15} in the seedlings	12.8	41.7	75.0	111.0
	$P_{45}K_{45}$ in the main application + two fertilizers N_{15} in the seedlings + N_{30} in the rosette-stemming phase	13.9	44.0	81.0	106.1
$LSD_{05\ general}$		0.23	0.56	0.52	0.57
$LSD_{05\ variety}$		0.12	0.28	0.26	0.29
$LSD_{05\ fertilizer}$		0.10	0.25	0.23	0.26

The height of plants of Tsarivna Pivnochi, Pidpecheretska and Oslava varieties during the seed ripening phase in the control ranged from 97.1 to 98.0 cm, with no significant difference. The reaction of all varieties to the mineral fertiliser application, both main application and foliar fertilization, was almost the same. The increase in plant height of all varieties, except Etalon and Oslava, in the rosette phase averaged 2.1-2.2 cm, in Etalon it was significantly lower, and in Oslava it was significantly higher. The greatest increase in plant height of all varieties in the phenological phases of growth and development was with the combined application of phosphorus-potassium fertilizers as the main and two-time foliar fertilization with nitrogen fertilizers. A significantly greater increase in plant height was noted in the interphase period " bud stage-flowering".

Variance analysis of the influence of the studied factors on the plant height during the cultivation of mustard seeds revealed that the greatest influence was the factor "fertilizer", in all plant growth and development stages (Figure 1).



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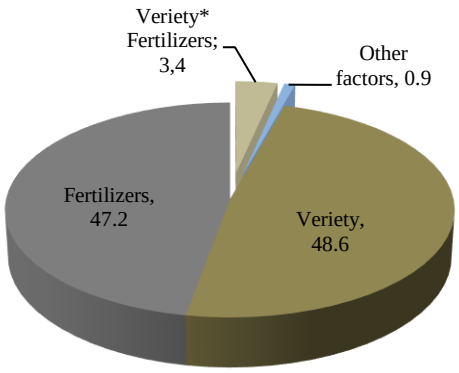

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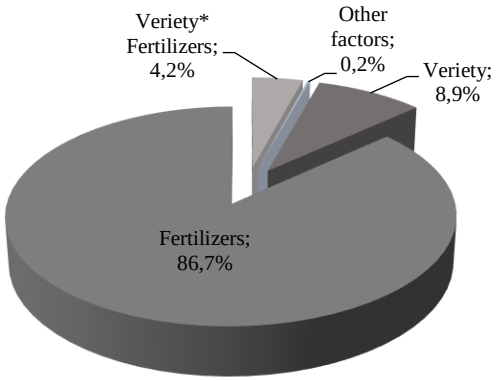

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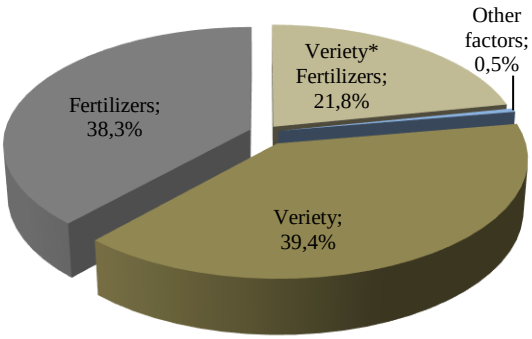

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Figure 1: Influence of factors on the formation of plant height by stages of plant growth and development (average for 2020-2023) showing: a) Rosette stage; b) Bud stage; c) Flowering stage; and d) Ripening stage

In the rosette stage, the influence of the "fertiliser" factor was 71.0%, the "flowering" factor – 86.7%, and in the bud and ripening stages, the influence of fertilizers was less and amounted to 47.2% and 38.3%, respectively. In the budding stage, the effect of the factor "variety" was the highest and amounted to 48.6% and in the ripening stage – 39.4%. The effect of the interaction of "fertiliser*variety" factors in all phases of plant growth and development was insignificant.

Melnyk and Zherdetska (2017) found that in grey mustard plants, when fertilised with $N_{30}P_{30}K_{30}$ and $N_{60}P_{60}K_{60}$, the number of first-order branches increased by 0.4 and 0.8 units compared to the control, and amounted to 3.7 and 4.1 units, respectively.
We observed a similar growth of pods and stems on mustard plants when phosphorus-potassium mineral fertilizers were applied as the main fertilizer, and mainly with foliar fertilization with nitrogen fertilizers, depending on the varietal characteristics. A significantly smaller number of pods was formed on plants in the control – without mineral fertilizers in all varieties (Table 2).

Table 2: The number of pods per plant, pcs. Depending on the genotype and mineral fertiliser application during the ripening phase (average for 2020–2023)

Variant – fertilizers	*Variety*				
	Tsarivna Pivnochi	*Etalon*	*Pidpecheretska*	*Ariadna*	*Oslava*
No fertilizer - control	66.8	54.4	61.8	69.6	69.2
$P_{45}K_{45}$ in the main application without fertilizing	80.1	69.7	73.4	81.8	74.8
$P_{45}K_{45}$ in the main application + fertilizer N_{15} in the seedlings	105.8	83.8	89.2	90.7	91.0
P45K45 in the main application + two fertilizing N_{15} in the seedlings + N_{30} in the rosette-stemming phase	118.7	96.3	101.3	106.0	107.1
$LSD_{05\ general}$	1.99				
$LSD_{05\ variety}$	0.99				
$LSD_{05\ fertilizer}$	0.89				

The highest number of pods in the control was in the varieties Ariadna and Oslava, respectively – 69.6 and 69.2 pieces, significantly less compared to the above varieties – in the variety Tsarivna Pivnochi – 66.8 pieces, the variety Pidpecheretska – 61.8 pieces and the least in the variety Etalon – 54.4 pieces. A similar dependence on the fertiliser use was observed. In addition to the control, the introduction of only phosphorus-potassium fertilizers in the main fertilizer provided a reliable increase in the pod number in all varieties compared to the control. The highest pod number was created on plants of varieties Ariadna - 81.8 pieces or 12.2 pieces more, and Tsarivna Pivnochi - 80.1 pieces or 13.3 pieces compared to the control, and the smallest - 73.4 pieces of the variety Pidpecheretska or 11.6 pieces less than in the control. Etalon variety's response to fertilisation was effective, which provided the greatest increase in pods (15.3 pieces) compared to the control.

Combined use of the main fertilizer and foliar fertilization provided a noticeable increase in pods both in comparison with the control and the application of fertilizers alone without fertilizing all varieties. One-time foliar fertilization resulted in the greatest

increase in pods compared to the control and the application of only the main fertilizer – the varieties Tsarevna Severa and Etalon, respectively – increasing by 39 and 29.4 pods. Two applications of foliar fertilization increased pods per variety, ranging from 36.4 to 51.9 pieces compared to the control. In contrast, the main fertilizer led to a smaller increase, varying from 12.1 pieces (Pidpecheretska) to 16.1 pieces (Oslava). The expediency of conducting two foliar fertilization should be determined by the increase in the yield of mustard seeds. Analysis of the factors that influenced the pod number showed that the greatest influence was the factor of "fertilizer" and amounted to 85.6%, the influence of the "variety" was less – 10.9% (Figure 2).

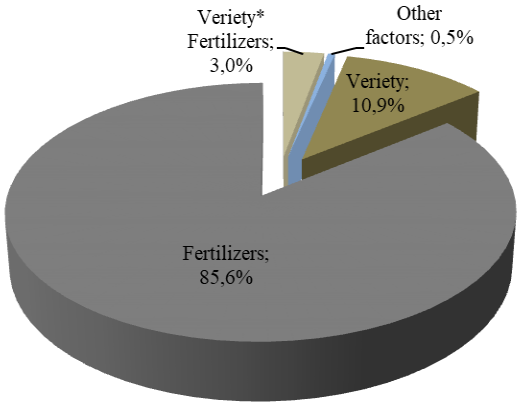

Figure 2: Influence of factors on pod formation depending on varietal characteristics and fertilization (average for 2020-2023)

Similar dependencies were found in the formation of mustard stems depending on the use of mineral nutrition and varietal characteristics. The smallest stem number was formed in the control – without fertilizers, and the use of mineral fertilizers provided a significant increase in all varieties (Table 3).

Table 3: Number of stems per plant, pcs. Depending on genotype and mineral fertiliser application during the ripening phase (average for 2020-2023)

Variant – fertilizers	*Variety*				
	Tsarivna Pivnochi	*Etalon*	*Pidpech-eretska*	*Ariadna*	*Oslava*
No fertilizer - control	3.1	2.6	3.4	3.9	4.0
$P_{45}K_{45}$ in the main application without fertilizing	4.3	3.4	4.8	4.8	4.9
$P_{45}K_{45}$ in the main application + fertilizer N_{15} in the seedlings	5.1	4.4	5.2	5.7	5.9
$P_{45}K_{45}$ in the main application + two fertilizing N_{15} in the seedlings + N_{30} in the rosette-stemming phase	6.0	5.0	6.1	6.5	6.6
$LSD_{05\ general}$	0.27				
$LSD_{05\ variety}$	0.14				
$LSD_{05\ fertilizer}$	0.12				

A significantly greater number of stems both in the control and under mineral nutrition was formed by varieties Oslava and Ariadna, no significant difference was found, the smallest – being by variety Etalon. The use of phosphorus-potassium fertilizers in the main fertilizer provided an increase in the number of stems of Oslava and Ariadna varieties by 0.9 pcs. or by 22.5 and 23.1%, respectively, compared to the control. The largest increase in stems was in the varieties Tsarivna Pivnochi – 1.2 pcs. or 38.7% and Pidpecheretska – 1.4 pcs. or 41.2%. The integrated use of the main fertilizer and one-time foliar fertilization provided a considerable increase in the number of stems of all varieties compared to the control and the main fertilization. The highest stem number was obtained with two-time foliar fertilization on the background of the main fertilizer.

The analysis of variance revealed that the greatest influence on the formation of mustard stems was the factor "fertilizer" – 74.7%, the influence of the "variety" was 22.4%, and the interaction of them and other factors was insignificant (Figure 3).

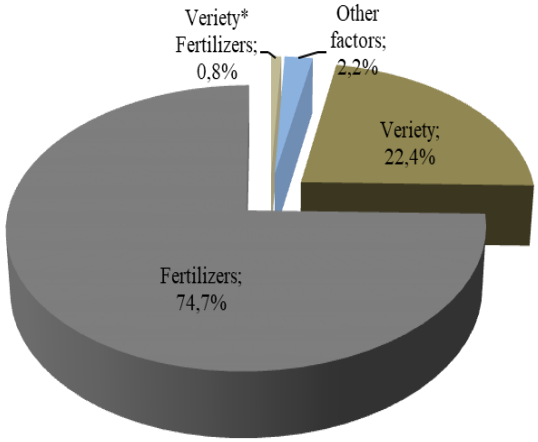

Figure 3: Influence of factors on stem formation depending on varietal characteristics and fertilization (average for 2020-2023)

Improvement of the yield structure indicators contributed to the increase in the seed productivity of mustard - if on average, the seed yield of the varieties significantly increased with the mineral fertilizers application compared to the control – without fertilizers, then the quality of seeds – germination energy and germination, when applying mineral fertilizers did not provide a significant increase in these indicators, they were at the level of the control (Table 4).

The weight of 1000 seeds, on the other hand, varied depending on the varietal characteristics and the use of mineral fertilizers. The highest weight of 1000 seeds (more than 4 g) was in the varieties Tsarivna Pivnochi, Pidpecheretska and Oslava. The highest weight of 1000 seeds was obtained with the combined use of phosphorus-potassium mineral fertilizers as the main fertilization and two foliar fertilizations with nitrogen fertilizers on the seedlings and in the rosette-stem phase. Increasing the weight of 1000 seeds depending on the genotype and the use of mineral fertilizers provided an increase in the yield of seeds of all varieties compared to the control.

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Table 4: Quality of mustard seeds depending on varietal characteristics and fertilizer application (average for 2020-2023)

Variant		*Germination energy, %*	*Germination, %*	*Mass of 1000 seeds, g*
Variety	*Fertilizer Application*			
Etalon	No fertilizer - control	94	95	3.17
	$P_{45}K_{45}$ in the main application without fertilizing	92	93	3.33
	$P_{45}K_{45}$ in the main application + fertilizer N_{15} in the seedlings	97	97	3.79
	$P_{45}K_{45}$ in the main application + two fertilizing N_{15} in the seedlings + N_{30} in the rosette-stemming phase	95	95	3.83
Tsarivna Pivnochi	No fertilizer - control	97	97	4.53
	$P_{45}K_{45}$ in the main application without fertilizing	97	98	4.65
	$P_{45}K_{45}$ in the main application + fertilizer N_{15} in the seedlings	98	98	4.76
	$P_{45}K_{45}$ in the main application + two fertilizing N_{15} in the seedlings + N_{30} in the rosette-stemming phase	97	98	4.72
Pidpech-eretska	No fertilizer - control	97	98	4.81
	$P_{45}K_{45}$ in the main application without fertilizing	95	96	4.58
	$P_{45}K_{45}$ in the main application + fertilizer N_{15} in the seedlings	94	95	4.81
	$P_{45}K_{45}$ in the main application + two fertilizing N_{15} in the seedlings + N_{30} in the rosette-stemming phase	96	96	4.89
Ariadna	No fertilizer - control	96	95	3.52
	$P_{45}K_{45}$ in the main application without fertilizing	96	96	3.67
	$P_{45}K_{45}$ in the main application + fertilizer N_{15} in the seedlings	97	97	3.81
	$P_{45}K_{45}$ in the main application + two fertilizing N_{15} in the seedlings + N_{30} in the rosette-stemming phase	97	97	3.99
Oslava	No fertilizer - control	96	96	4.74
	$P_{45}K_{45}$ in the main application without fertilizing	97	97	4.67
	$P_{45}K_{45}$ in the main application + fertilizer N_{15} in the seedlings	96	97	4.84
	$P_{45}K_{45}$ in the main application + two fertilizing N_{15} in the seedlings + N_{30} in the rosette-stemming phase	95	96	4.96
$LSD_{05\ general}$		1.4	1.3	0.28
$LSD_{05\ variety}$		0.7	0.7	0.14
$LSD_{05\ fertilizer}$		0.6	0.6	0.13

This study showed that plant density and fertilization had a significant impact on black mustard yields. Gubenko and Lyubchych (2020) have determined that in the Right-Bank Forest-Steppe of Ukraine on grey forest light loamy soils, the mineral fertiliser application even in small quantities (60 kg/ha of P and 90 kg/ha of K) led to an increase in seed yields – by 0.84 t/ha without fertilization and by 0.77 t/ha with fertilization. The highest increases in seed yields were observed with the combined application of nitrogen, phosphorus and potassium, which amounted to 0.60–1.06 t/ha (without micro fertilizer) and 0.48–0.98 t/ha (with micro fertilizer) compared to the control (without fertilizer). According to Melnyk *et al.* (2019), in the North-Eastern Forest-Steppe of Ukraine, the introduction of $N_{30}P_{30}K_{30}$ and $N_{60}P_{60}K_{60}$ provided a significant increase in the yield of white mustard to 1.92 and 2.13 t/ha, which is 0.34 and 0.55 t/ha more than in the control, respectively.

According to the results of our research, the greatest increase in yield was obtained with the combined application of the main phosphorus-potassium fertiliser with two fertilisations with nitrogen fertilisers (Table 5). The introduction of $P_{45}K_{45}$ with two fertilisers N_{15} and N_{30} in the rosette-stemming phase increased the yield by 0.37-0.52 t/ha or 0.19-0.26 t/ha compared to the variant where the plants were not fertilised. The correlation and regression analysis revealed an average correlation between the increase in the weight of 1000 seeds and the increase in seed yield, the correlation coefficient is 0.61.

Table 5: Increase in seed yield (t/ha) compared to the control, depending on the genotype and mineral fertiliser application (average for 2020–2023)

Variant – fertilizers	*Variety*				
	Tsarivna Pivnochi	*Etalon*	*Pidpech-eretska*	*Ariadna*	*Oslava*
$P_{45}K_{45}$ in the main application without fertilizing	0.26	0.14	0.18	0.20	0.27
$P_{45}K_{45}$ in the main application + fertilizer N_{15} in the seedlings	0.48	0.41	0.35	0.43	0.39
$P_{45}K_{45}$ in the main application + two fertilizing N_{15} in the seedlings + N_{30} in the rosette-stemming phase	0.52	0.46	0.37	0.47	0.43
$LSD_{05\ general}$	0.04				
$LSD_{05\ variety\ fertilizer}$	0.02				

Conclusion

The study was aimed at finding out the peculiarities of the formation of crop structure elements, yield and quality of mustard seeds depending on varietal characteristics and mineral nutrition. It was found that the use of mineral fertilizers provided a significant increase in the yield structure indicators – plant height at all stages of growth and development, and the number of stems and pods per plant, which contributed to an increase in mustard yield and seed quality depending on varietal characteristics. The combined application of the main fertilizer and foliar feeding provided a significant increase in stems and pods both in comparison with the control and the application of fertilizer alone without feeding all varieties. It was highest with the combined use of phosphorus-potassium mineral fertilizers as the main fertilizer and two foliar fertilizers

with nitrogen fertilizers on the seedlings and in the rosette-stem stage. Analysis of variance revealed that the mustard height was most significantly influenced by the factor "fertiliser" with an influence index in the range of 38.3-86.7%, depending on the phenological phase of plant growth and development. It was found that the greatest increase in plant height of all varieties was observed with the main application of $P_{45}K_{45}$ with two fertilisations of N_{15} after germination and fertilisation of N_{30} in the rosette-stem phase. In particular, in the Oslava variety, the height of plants in the ripening phase increased by 8.1 cm compared to the variant without fertiliser. Similar results were obtained when analysing the factors that influenced the number of pods and stems. It was determined that the influence of the "fertiliser" factor was the largest, with values of 85.6% and 74.7%, respectively. The number of knots and stems in all varieties was significantly lower in the variant without mineral fertilisers. Thus, with the main application of $P_{45}K_{45}$ with two fertilisations of N_{15} after germination and fertilisation of N_{30} in the rosette-stem phase, the Tsarevna Severa variety formed 51.9 more pods and 2.9 more stems than the control without fertilisation. On average, the seed yield of the varieties significantly increased by 0.24 t/ha with the mineral fertiliser application compared to the control without fertilisers and amounted to 0.41 t/ha with the main use of $P_{45}K_{45}$ with N_{15} fertilisation on the germination stage and 0.45 t/ha with the main use of $P_{45}K_{45}$ with two fertilisations of N_{15} on the germination stage and N_{30} fertilisation in the rosette-stemming stage.

Taking into account the results obtained, it is advisable to continue these studies using complex water-soluble fertilisers that include macro- and microelements, which can reduce the cost of seeds.

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Conceived and designed the research or analysis	Yes	Yes	No	Yes	No
Collected the data	Yes	No	No	No	No
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